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Chapter 12

MECHANICAL DAMAGE DISTANCES FOR SURFACE SHIPS AND SUBMARINES SUBJECTED TO NUCLEAR EXPLOSIONS [redacted]

[redacted] INTRODUCTION [redacted]

12-1 Damage Mechanisms [redacted]

[redacted] An air burst nuclear weapon may cause mechanical damage to surface ships by air burst, thermal radiation, ionizing radiation, and the electromagnetic pulse. Ship operations may also be affected by personnel casualties; however, only mechanical damage is considered in this chapter.

[redacted] An underwater burst may cause damage to surface ships by the shock wave in the water, by the water column or plumes thrown up by the burst, by the surface gravity waves produced, or by the ionizing radiation from the base surge, fallout, or contaminated water pool. As for an air burst, the ship status may be affected by personnel casualties; however, only mechanical damage is considered in this chapter.

[redacted] An underwater burst may cause damage to submerged submarines by the shock wave in the water, and, in special shallow water cases, by collision with the ocean bottom induced by the waves.

12-2 Damage Classification [redacted]

[redacted] Damage to surface ships and submarines is described by the degree of impairment of three major ship capabilities: seaworthiness, mobility, and weapon delivery. Complete loss of a capability is characterized as 100-percent impairment; no impairment is considered 0 percent. Levels of impairment of 90 percent and 10 percent are intended to signify nearly complete and slight impairment, respectively. These degrees of impairment should be interpreted as being the midpoints of a band of percent impairments.

[redacted] The concept of degree of capability impairment is closely related to the fact that, for any given burst condition, a continuous spectrum of degrees of damage would be inflicted on ships of the same type located over a continuous spread of ranges from the burst. A ship is so complex a system that it is not possible to predict damage precisely for any given attack situation. Another consideration is that the crew of a damaged ship will attempt to repair damage; i.e., to decrease the degree of impairment of capability as quickly as possible. The time consumed by such repair is a vital aspect of the total damage assessment, but available knowledge does not justify an attempt to consider it in detail.

[redacted] Damage ranges are given in this chapter in terms of zones within which varying degrees of impairment of each capability are to be expected. The outer boundary of a given zone corresponds to slight, and possibly temporary, impairment of the indicated capability; the inner boundary corresponds to nearly complete impairment that would require shipyard facilities for repair. The locations of the boundaries are determined by damage criteria derived from experimental data. There are, however, uncertainties involved as a result of a lack of sufficient experimental data. It is estimated that uncertainties concerning damage criteria cause uncertainties in the boundary locations on the order of 15 to 30 percent.

12-3 Seaworthiness Impairment [redacted]

[redacted] The degrees of seaworthiness impairment are defined as follows:

- 100 percent: The ship or submarine is sunk.
- 90 percent: The ship is in danger of sinking,

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[redacted] capsizing, or breaking up as a result of widespread, uncontrollable flooding or the loss of girder strength. Danger is present even in normal weather, but there is some chance of saving the ship. As a result of damage to its structure or to its buoyancy-control gear, a submarine will be in danger of settling to the bottom.

- 10 percent: Slight plastic deformation of the structure that may cause minor leakage. Hogging or sagging, or topside structural damage can occur, but not to an extent sufficient to endanger the ship in stormy weather. For submarines, this degree of impairment includes that damage that can at worst reduce the maximum safe diving depth slightly, but otherwise allows the submarine to submerge in a controlled manner.
- 0 percent: No plastic deformation of structure and no leakage.

12-4 Mobility Impairment [redacted]

[redacted] The degrees of mobility impairment are defined as follows:

- 100 percent: The ship or submarine lacks any ability to operate its propulsion devices.
- 90 percent: The ship can at best just barely maintain steerageway in a desired direction, either as a result of damage to main propulsion machinery and control gear, or as a result of personnel casualties.
- 10 percent: Slight loss of ability to achieve top speed and/or to maneuver normally, as a result of damage or personnel casualties.
- 0 percent: No impairment of mobility.

12-5 Weapon Delivery Impairment [redacted]

[redacted] The degrees of weapon delivery impairment are defined as follows:

- 100 percent: The ship or submarine cannot release its weapons.
- 90 percent: Weapons can be released, but it is almost impossible to deliver them effectively because the ship's target-acquisition and communication equipment are inoperative, either as a result of damage to equipment or to topside structure, or as a result of personnel casualties.
- 10 percent: Slight reduction in weapon-delivery efficiency as a result of damage to equipment or topside-structure or as a result of personnel casualties.
- 0 percent: No loss.

SECTION I

[redacted] DAMAGE TO SURFACE SHIPS FROM AIR BURSTS [redacted]

[redacted] BLAST DAMAGE [redacted]

12-6 General [redacted]

[redacted] Air blast damage may be significant for surface ships when the burst is at or above the water surface. The following general description of air blast effects on ships is applicable to existing Navy ships.

[redacted] At close ranges, air blast can cause hull rupture that can result in flooding and sinking. Hull rupture appears likely to begin near the waterline on the side facing the blast. The main hull of existing Navy ships is, however, stronger than the superstructure and equipment. At ranges beyond those at which hull rupture is likely to occur the main effect of air blast is to distort, rupture, or carry away light structures and equipment vulnerably exposed above the waterline, and to cause casualties among topside personnel. Such damage can cause complete impairment of the weapon delivery capability. Blast pressures penetrating through weather openings of ventilation systems and stack-uptake systems can cause damage to interior equipment and compartments, and also to boilers; the latter may result in immobilization. The distortion of weather bulkheads may cause fracture or render interior equip-

[redacted] ment mounted on or near them useless. Similarly, the suddenly applied blast loading induces rapid motion of the structures that in turn may cause shock damage to interior equipment. Equipment in the superstructure is most vulnerable to these types of damage, although shock motions may be felt throughout the ship. Air blast also may cause the ship to roll and possibly capsize; this effect is most pronounced for broadside attack by large weapons (multimegaton).

12-7 Damage Criteria [redacted]

[redacted] Peak overpressure is used as the sole parameter to describe attack severity, except for the capsizing effect. This criterion is acceptable for most existing surface ship structures, since the effects of the blast wave are practically independent (within predictive accuracies) of the blast wave duration, i.e., weapon yield, for weapons larger than a certain size. Mechanical damage criteria in terms of peak overpressure for some existing Navy ships are given in Table 12-1. The estimates shown in Table 12-1 are derived from CROSSROADS ABLE and SAILOR HAT data, as well as from some structural analyses.

12-8 Damage Distances [redacted]

[redacted] Distances at which damage is expected to occur from a 1-Mt air burst are shown in Figure 12-1. The curves define zones in which impairment of a stated capability occurs. The outer boundary of the zone indicates slight (10 percent) impairment; the inner boundary indicates almost complete (90 percent) impairment. At distances beyond the outer boundary of a zone there is essentially no impairment of the stated capability. At ranges within the inner boundary of a zone the impairment is essentially complete.

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Problem 12-1 Calculation of Air Blast Damage Distances to Surface Ships as a Result of Air Bursts

[redacted] Figure 12-1 shows families of curves that define zones within which a stated degree of impairment is expected to occur to representative Naval ships from a 1 Mt air burst.

[redacted] *Scaling.* Air blast damage distances for yields other than 1 Mt as follows:

$$\frac{d_1}{d_2} = \frac{h_1}{h_2} = \frac{W_1^{1/3}}{W_2^{1/3}} .$$

where d_1(yd) is the distance from surface zero (SZ) for a given degree of damage for yield W_1 (kt) at a height h_1 (ft), and d_2 (yd) is the range for a given degree of damage for a yield W_2 (kt) at height h_2 (ft). This scaling law is applicable within predictive accuracies, provided the weapon yield is larger than about 1 kt.

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[redacted] *Reliability:* The distance to which a given degree of damage will occur should fall within the bands indicated in Figure 12-1 for the classes of ships listed in Table 12-1. The damage-distance bands provide a rough estimate for ships of similar types.

[redacted] *Related Material:* See paragraphs 12-6 through 12-8 and Section I, Chapter 2.

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12-9 Capsizing from Blast [redacted]

[redacted] Figure 12-2 shows estimates of ranges for capsizing various types of ships as a result of air blast from surface bursts. The distances are shown as functions of weapon yield, since cube-root scaling does not apply. The estimates are based on theoretical calculations alone, since experimental data are not available on capsizing. The width of the bands in Figure 12-2 corresponds to the difference between two sets of theoretical calculations. The ranges are valid for broadside attack only. Air blast will not capsize a ship in a fore-and-aft attack direction. For an attack direction of 45 degrees off the bow or stern, it is roughly estimated that capsizing ranges are 5 to 10 percent smaller. The capsizing distances from an air burst may be greater than those shown for a surface burst in Figure 12-2. For a given yield the increase in range can be determined approximately by assuming that the capsizing overpressure is independent of burst height (within the Mach region), and then by referring to curves of range versus height of burst for constant overpressures (see Section I, Chapter 2).

[redacted] DAMAGE FROM OTHER AIR BURST PHENOMENA [redacted]

12-10 Thermal Radiation [redacted]

[redacted] Material exposed to thermal radiation may be charred, scorched, ignited, melted, or otherwise changed. In addition, the heat may affect the mechanical properties of structural metals by annealing (reduction of strength). The rapid rate of delivery of thermal energy may induce large temperature gradients, and the resulting thermal stresses may produce effects such as surface spalling or cracking, and/or permanent distortions of structures or structural elements. Weakening of structural elements may cause weapon system and superstructure components to be more vulnerable to the air blast, which arrives after most of the thermal exposure has been received. Distortion of radar antennas and other superstructure components may cause functional impairment.

[redacted] Thermal radiation can affect only the exposed topside personnel and material of a surface ship. Any opaque object along the fireball-to-target line of sight will furnish protection from thermal radiation. Topside personnel or material in the shadow or the ship's structural or topside gear would be shielded from thermal radiation.

[redacted] Fires are not likely to originate except perhaps when severe, and probably overriding, blast damage is also sustained. Normally there is insufficient combustible material topside on combatant ships to sustain fire. Possible exceptions may be vessels carrying inflammable liquids, which may spill as a result of the blast (aircraft carriers), and vessels carrying combustible deck loads (cargo ships). Water washdown systems, installed primarily for protection against deposited radioactive debris, should reduce fire hazards and thermal radiation damage, provided they are turned on prior to the burst.

[redacted] The main steel hulls of naval ships are not likely to be weakened by thermal radiation, except when severe, and probably overriding, blast damage is also sustained. Of the metallic components in use on present ships, those made of aluminum may be most susceptible to thermal radiation effects (annealing, melting). The effect will be greatest on thin aluminum components. Aluminum plates of alloy 5456-H321 less than 5/16 inch in thicknesses may suffer more than 50-percent loss of strength prior to the arrival of the blast at the 10-psi range from a 1-Mt burst. Lightweight aluminum-alloy components, which have been used extensively in radar antennas as support members, reflector elements, and wave guides, appear to be susceptible to melting, sagging, and buckling when exposed to free-field thermal radiation at the 10 psi overpressure

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[redacted] range. Thicker aluminum-alloy materials, which have been used for main superstructures, could be weakened significantly prior to blast arrival.

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12-11 Damage from Nuclear Radiation and Electromagnetic Pulse [redacted]

[redacted] Electronic system components are the only pieces of equipment subject to damage from nuclear radiation or the electromagnetic pulse (EMP). General effects of these phenomena on electronic systems are discussed in Sections VII and VIII of Chapter 9. References to more specific treatments of the effects of these phenomena are provided in the same sections of Chapter 9.

SECTION II
[redacted] SURFACE SHIP DAMAGE FROM UNDERWATER BURSTS [redacted]

[redacted] DAMAGE FROM THE SHOCK WAVE IN THE WATER [redacted]

[redacted] The shock wave can affect surface ships by deforming hulls plastically, by inducing damaging shock motions in equipment, and by subjecting personnel to injurious shock motions. The degree of hull deformation determines the degree of impairment of seaworthiness, whereas equipment failures determine the degree of impairment of the mobility and weapon delivery capabilities. The principal shock motions induced in surface ships are in the vertical direction. For current surface ships, personnel injuries caused by shock motions probably are not a significant feature in the overall impairment, and no attempt is made herein to estimate the number of personnel casualties or the effect of these casualties on the impairment of capability.

12-13 Damage Criteria [redacted]

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12-14 Damage Distances [redacted]

[redacted] The damage distances resulting from the use of the above criteria are shown in Figures 12-3 through 12-5 for 1 kt, 10 kt, and 1 Mt underwater bursts respectively. The distances are given by bands defining zones in which impairment of a stated capability occurs. The outer boundary of the zone indicates slight (10 percent) impairment; the inner boundary of the zone indicates almost complete (90 percent) impairment. At distances beyond the outer boundary of a zone there is essentially no impairment of the stated capability. At distances within the inner boundary of a zone, the impairment is essentially complete.

[redacted] The damage distances were computed for calm isovelocity water, i.e., no variation of temperature with depth. Allowance was made for anomalous surface reflection (nonlinear reflection occurring when the shock wave propagates nearly parallel to the surface). The possible effect of ship orientation with respect to the direction of shock wave propagation was not considered, nor was the possible effect of different drafts of vessels fully considered.

12-15 Effect of Ocean Environment on Damage Ranges [redacted]

[redacted] The shock wave propagating along the direct "line-of-sight" path between the burst point and the surface ship target may not be the governing damage phenomenon in all cases. When the water depth is greater than the burst depth, it is possible, in some cases, for the shock wave reflected from the bottom to produce more severe damage to equipment than the direct shock wave. Although the peak pressure of the reflected shock wave is less than that of the direct shock wave, it propagates in a more nearly vertical direction and, hence, is more effective in producing the vertical shock motions that control the degree of damage to equipment. The reflected wave is most likely to control damage distances for weapon-delivery and mobility capabilities when the burst occurs fortuitously at a certain depth. The bottom reflected wave is not likely to control ranges for impairment of seaworthiness.

[redacted] It is not possible to predict the effects of the reflected shock wave without extensive knowledge of the configuration and structure of the bottom in the vicinity of the detonation. However, certain general statements can be made. If the sea bottom profile is concave, the reflected shock wave will be focused, and ships in certain local areas may sustain a higher degree of damage than would otherwise be expected. Since this will be true only for local areas of the water surface and since the effect depends on the exact bottom configuration, such an event is regarded as a freak occurrence. The sea bottom may be plane, with no appreciable curvature, but nevertheless may slope. If a surface ship is down-slope from surface zero, damage will tend to be less than for a flat bottom at a depth equal to the water depth below the ship. If a surface ship is up-slope from surface zero, damage will tend to be greater than for a flat bottom at a depth equal to the water depth below the ship.

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[redacted] Even if the sea bottom is essentially flat, the strength of the reflected shock wave will depend on the composition of the bottom. The shock may be less for mud than for sand, but it may be greater for rock than for sand. Figures 12-3 through 12-5 provide means for estimating distances at which impairment of weapon delivery and mobility may occur as a result of the bottom reflected wave. The estimates are based on the assumption of a flat sea bottom with a reflection coefficient and a relation between reflection coefficient and incident angle similar to that observed at the site of the WAHOO test of Operation HARDTACK. In Figures 12-3 through 12-5, the reflected wave damage distances are shown as functions of the image burst depth. As illustrated in Figure 12-3, the image burst depth is obtained by adding the depth of the bottom to the height of the burst above the bottom, or, equivalently, doubling the depth of the bottom and subtracting the depth of the burst. When determining the distances for impairment of weapon delivery and mobility when the burst and water depths are within the limits given in Table 12-3, the ranges should be found for both the direct shock wave and the bottom reflected shock wave, and the larger value should be used.

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[redacted] The ambient sea waves existing just prior to the burst may decrease the damage caused by the shock wave. Although evidence of this effect is too inconclusive to allow quantitative estimates, it appears likely that for otherwise identical conditions, ship damage caused by the shock wave will decrease somewhat as the height of the ambient sea wave increases.

[redacted]

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Problem 12-2 Calculation of Shock Wave Damage Distances to Surface Ships as a Result of Underwater Bursts

[redacted] Figures 12-3 through 12-5 show families of curves that define zones within which a stated degree of impairment is expected to occur to representative Naval ships from the indicated weapon yields burst underwater. Each figure has an "a" portion that shows the damage distance relations for the direct shock wave and a "b" portion that shows the relations for the bottom-reflected shock wave.

[redacted] *Scaling.* Water shock damage distances for yields other than those indicated in Figures 12-3 through 12-5 scale as follows (note that the range of yield applicability is shown on each figure):

$$\frac{d_1}{d_2} = \frac{h_1}{h_2} = \frac{W_1^{1/3}}{W_2^{1/3}}$$

where d_1 (yd) is the distance from surface zero (SZ) for a given degree of damage for yield W_1 (kt) at a depth of h_1 (ft), and d_2 (yd) is the distance for the same degree of damage for yield W_2 (kt) at depth h_2 (ft). Image-burst depths and sea bottom depths should be scaled in the same manner as burst depth h.

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[redacted] *Related Material:* See paragraphs 12-13 through 12-15, and Section IV, Chapter 2.

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[redacted] DAMAGE FROM OTHER UNDERWATER BURST PHENOMENA [redacted]

[redacted] Water waves (gravity waves produced by a burst) can conceivably be a contributing factor in causing mechanical damage to surface ships, especially to a ship already weakened by air and water shock. Waves might cause flexural (bending of the ship's longitudinal girder) damage to ships oriented end-on to the burst, or capsizing of ships oriented beam-on to the burst. Wave damage has not been observed experimentally in connection with bursts in deep water, but some wave damage appears to have occurred in the shallow-water CROSSROADS BAKER test. A complete theoretical investigation of ship response to explosively generated waves has not been carried out. Ship response will depend on the wave periods and heights as well as ship characteristics, heading, and speed. Present indications are that the significance of waves in deep water will be minor relative to other damage phenomena (water shock wave for underwater bursts, air blast for surface bursts.) Waves in shallow water may be more significant in producing damage, since such waves may be steeper, particularly if the water depth is shoaling in the direction of wave propagation.

[redacted] The water column or plumes thrown up by an underwater burst are not likely to cause significant mechanical damage to surface ships, since, for present ships, the water shock wave damage distances are greater. The highly radioactive base surge associated with the column or plume may be a hazard to personnel in some cases.

SECTION III

[redacted] SUBMARINE DAMAGE FROM UNDERWATER BURSTS [redacted]

[redacted] DAMAGE FROM THE SHOCK WAVE IN THE WATER [redacted]

[redacted] The types of damage caused to submarines by the shock wave are generally similar to those caused to surface ships, i.e., they can be classified as hull damage and as shock damage. The hull damage can range from slight plastic deformation of hull plating to rupture of the pressure hull, with subsequent sinking of the submarine. Shock damage to interior equipment, caused by the sudden motion, may result in impairment of the mobility and weapon delivery capabilities. Best available evidence indicates that present operational submarines (submerged) will be lost or severely impaired mechanically before significant levels of personnel casualties are produced among the crew. [redacted]

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12-16 Damage Criteria [redacted]

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12-17 Damage Distances [redacted]

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[redacted] The damage ranges were computed for calm isovelocity water, i.e., no variations of temperature. Allowance was made for anomalous surface reflection (nonlinear reflection occurring when the shock wave propagates nearly parallel to the surface). The possible effect of submarine orientation with respect to the direction of shock wave propagation was not considered.

12-18 Effect of Ocean Environment on Damage Ranges [redacted]

[redacted] The shock wave reflected from the sea bottom is less significant for submarines than for surface ships. In most cases, submarine damage ranges are not affected by the reflected wave. This is because the reflected wave will always be of lower pressure than the direct wave since it has to travel over a longer distance and suffer reflection losses. The fact that it impinges on the submarine at a different angle is in itself irrelevant (unlike the situation for surface ships), because the damaging effect is essentially independent of the angle of attack.

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[redacted] Refraction of the shock wave will occur in deep water when a sharp change in water temperature with depth exists (thermocline). Refraction may affect damage ranges for submerged submarines more significantly than it will for surface ships, since, under certain conditions, damage ranges can be increased appreciably. Although information on the effects of refraction is limited, certain generalizations can be made, which are believed to hold true under most conditions. If the submarine is above the thermocline, the situation is similar to that of a surface ship, i.e., the range at which a certain level of damage is produced is likely to be reduced (see Section II). If both the submarine and the burst are below the thermocline, damage ranges may be increased appreciably under some conditions. The effect of refraction is most significant in local areas where focusing occurs. Outside these areas, the effect is generally small and can be ignored in many cases. In general, the effects of refraction will increase with range from the burst and thus with weapon yield.

[redacted] DAMAGE FROM OTHER UNDERWATER BURST PHENOMENA [redacted]

[redacted] The shock wave usually will be the controlling damage phenomena for submarines. However, gravity waves generated by the underwater burst in some cases conceivably could cause damage. In deep water a submarine should more or less follow the wave motion, and since relatively small accelerations are involved in this case, no damage should result in addition to that caused by the shock wave. In shallow water a submarine close to the bottom could be carried by the wave motion into collision with boulders or protrusions from the sea bed. The worst danger from gravity waves such as those that could be produced if the water depth is shoaling in the direction of wave propagation. The turbulent water involved in this case could cause the submarine to impact against the bottom. Quantitative information is not presently available concerning the damage potential of gravity waves against submarines.

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Problem 12-3 Calculation of Damage Distances for Submarines from Underwater Bursts

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Scaling. Damage distances for shock wave damage to submarines can be obtained for yields intermediate between those shown in Figures 12-6 through 12-13 by employing the following approximate scaling laws. Ranges for weapon delivery and mobility impairment can, within the range of yield indicated in each figure, be obtained from

$$\frac{d_1}{d_2} = \frac{h_1}{h_2} = \frac{W_1^{1/3}}{W_2^{1/3}}$$

where d_1 (yd) is the damage distance for yield, W_1 (kt) burst at a depth h_1 (ft) and d_2 (yd) is the corresponding damage distance for yield W_2 (kt) at a burst depth of h_2 (ft). During this scaling process the submergence depth of the submarine is kept constant.

(U) The above indicated cube root scaling law applies to distances for impairment of seaworthiness also, provided the yield is greater than 100 kt. For yields smaller than 100 kt in the indicated ranges, it is more accurate to use a square root scaling law for seaworthiness impairment

$$\frac{d_1}{d_2} = \frac{h_1}{h_2} = \frac{W_1^{1/2}}{W_2^{1/2}}$$

where the nomenclature is the same as that used previously. Again, the depth of submergence of the submarine is kept constant during the scaling process.

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[redacted] *Reliability:* Figures 12-6 through 12-13 provide reasonable estimates for submarine damage criteria described in paragraph 12-16 for the specific submergence depths and yields for which the figures are provided. In view of the approximate nature of the scaling of damage distance with both yield and submergence depth, no firm estimate of overall reliability can be made.

[redacted] *Related Material:* See paragraphs 12-16 through 12-18 and Section IV, Chapter 2.

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